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AE9/AP9/SPM: NEW MODELS FOR RADIATION BELT AND SPACE PLASMA SPECIFICATION

W. Robert Johnston, et al.

05 May 2014

Briefing Charts

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14. ABSTRACT

A new set of models for the flux of particles in the Earth's inner magnetosphere has been developed for use in space system design and other applications requiring a climatological specification. Denoted AE9, AP9, and SPM for energetic electrons, energetic protons and space plasma, respectively, the models are derived from 33 data sets measured by satellite on-board sensors. These data sets have been processed in a manner to create maps of the particle fluxes together with estimates of uncertainties due to both imperfect measurements and space weather variability. Furthermore, the model architecture permits the Monte-Carlo estimation of the time evolution of fluxes and derived quantities, e.g. the median and 95th percentile, along an arbitrary orbit. An overview of the model will be presented, addressing in particular the latest AE9/AP9 version release.

15. SUBJECT TERMS
Energetic electrons, energetic protons, space plasma, Radiation Model, AE9, AP9, SPM, space craft design

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AE9/AP9/SPM: New Models for Radiation Belt and Space Plasma Specification

05 May 2014

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Integrity ★ Service ★ Excellence

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Outline

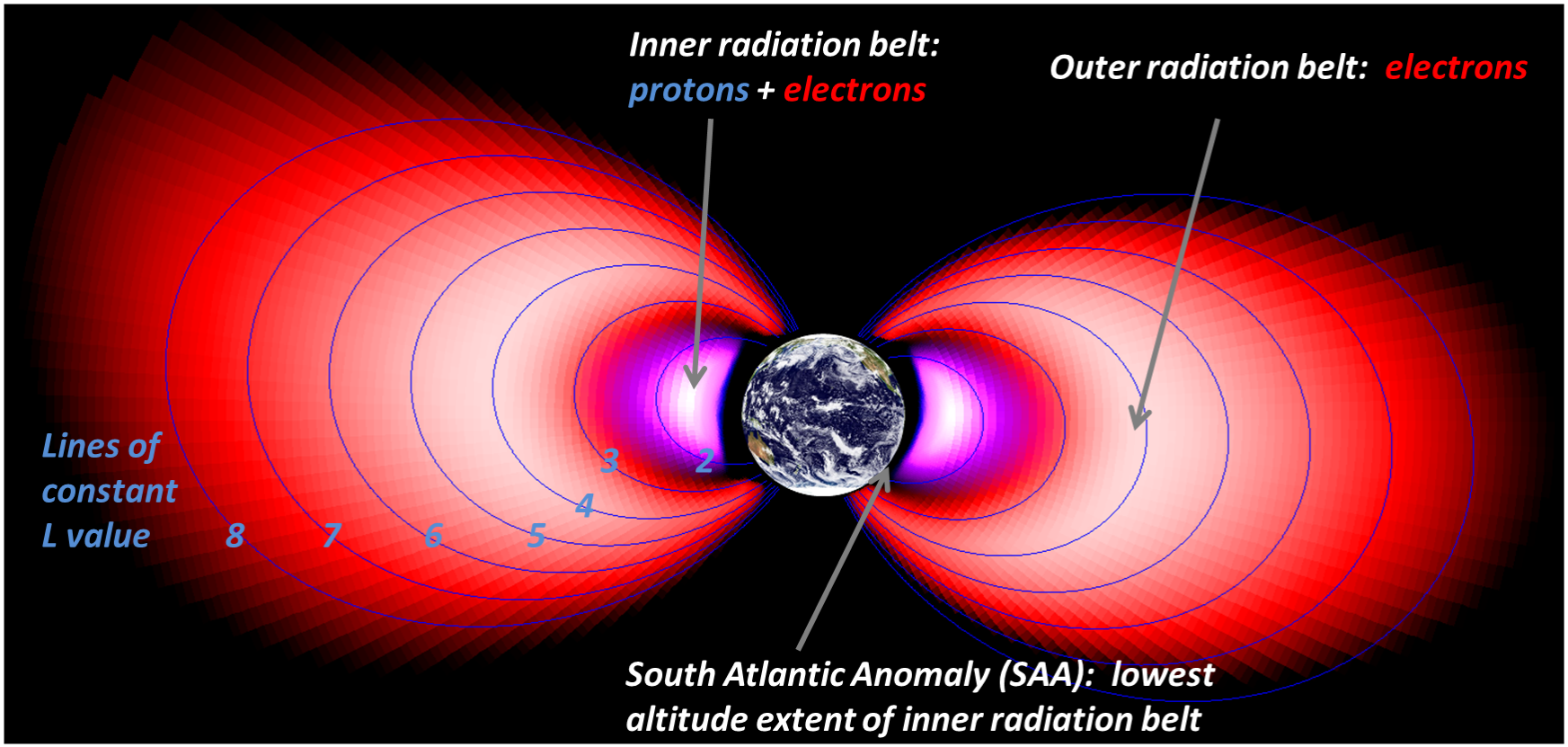
- Introduction
- Overview of AE9/AP9/SPM
- Model Application
- Validation and Comparisons
- Current & Future Releases
- Summary

Introduction to AE9/AP9/SPM

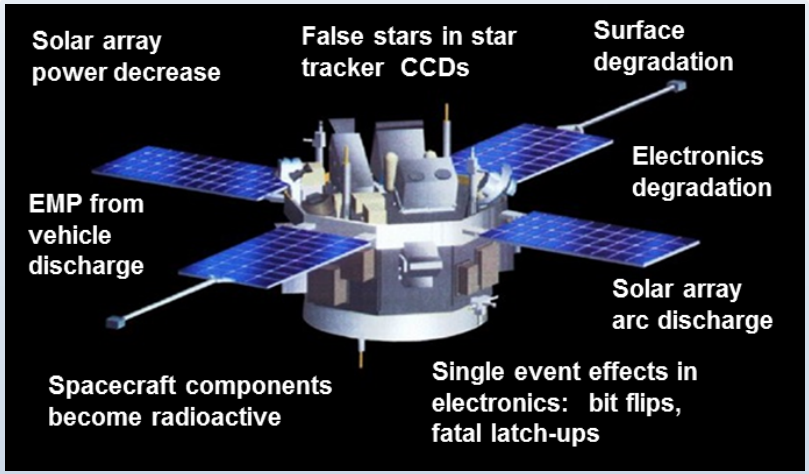
AE9/AP9/SPM is a suite of empirical models describing the trapped electron, proton, and plasma in the near earth space environment

- **AE9/AP9/SPM meets the satellite and space instrumentation design community's need for radiation environment specification model**
  - **Responsive tool with expanded range of features not available with legacy models**
  - **Uses the most up-to-date data available**
  - **Introduces quantitative statistics for use in design efforts**

Near-Earth Radiation Environment

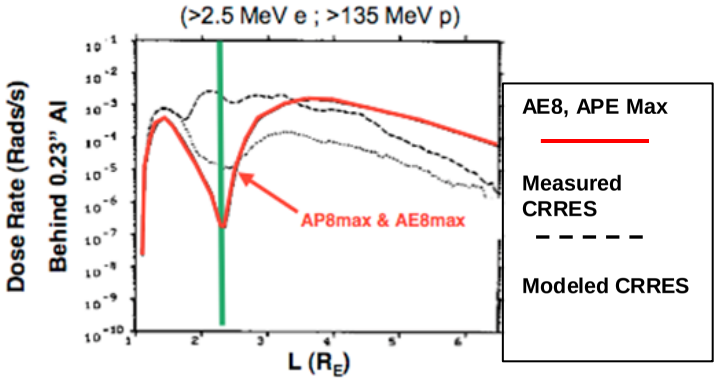


Need for Accurate Near-Earth Radiation Environment Estimations



Energetic protons, electrons and plasma pose a wide range of hazards to spacecraft and components

These hazards are dynamic and sometimes not accurately captured in legacy models



For MEO orbit (L=2.2), #years to reach 100 kRad:

- Quiet conditions (NASA AP8, AE8) : 88 yrs
- Active conditions (CRRES active) : 1.1 yrs

AE8 & AP8 under estimate the dose for 0.23'' shielding

Legacy Space Environmental Electron and Proton Models

AE8 & AP8 electron and proton empirical models are the most widely used of the various legacy models

- These are capable models, but do not meet emerging needs of the design community

- AE8/AP8 lacked the ability to trade actual environmental risks like other system risks
  - AE8/AP8 could never answer questions such as “how much risk can be avoided by doubling the shielding mass?”
- Inaccuracies and lack of indications of uncertainty
  - Creates the necessity of excessive margin in designs
- No plasma specification
  - Unknown surface dose effects
- No natural dynamics
  - Not present are environments for internal charging or worst case proton effects, such as single event effects (SEEs)

AE9/AP9/SPM Empirical Radiation Belt and Space Plasma Model Suite

AE9/AE9/SPM suite provides advanced capabilities for estimating the natural trapped radiation environment in near-Earth Space for satellite design

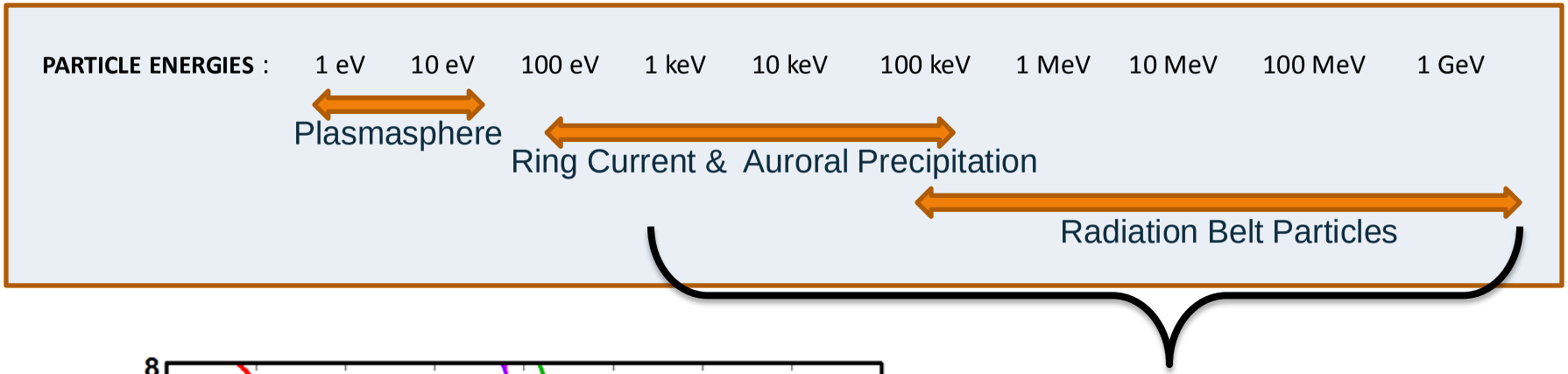
- **Unprecedented coverage in energies and particle types addressing major space environmental hazards**
- **Includes uncertainties and dynamics that have never been available for use in design**
  - **Data-based statistics quantifying uncertainties from both measurements and space weather variability**
  - **Estimate design margins (95th percentile rather than arbitrary factors)**
- **Dynamic scenarios allow users to create worst cases for internal charging, single event effects, and impacts on mission life**

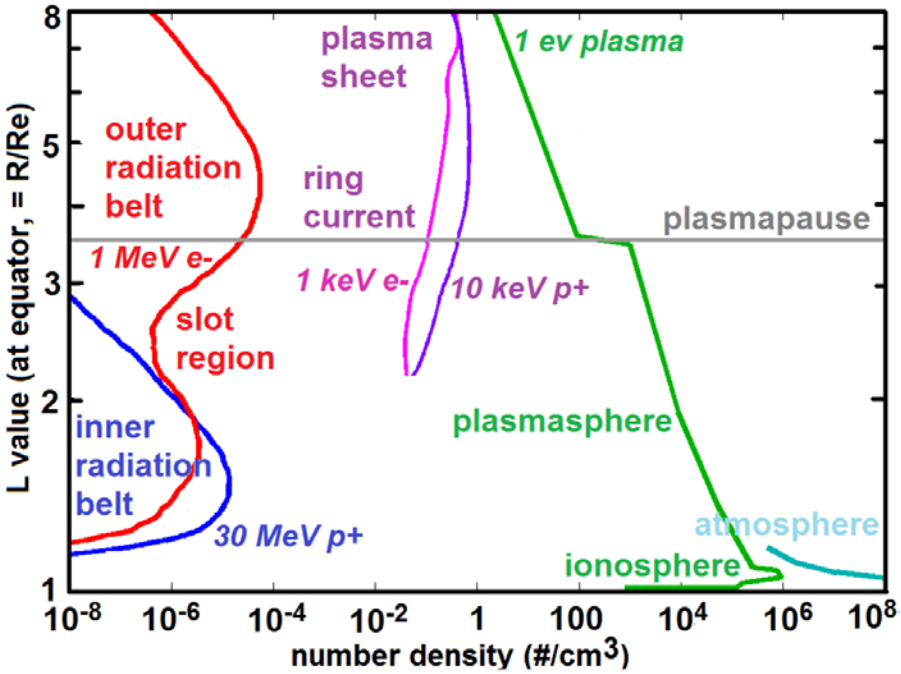
AE9/AP9/SPM Suite Coverage

MODEL	AE9	AP9	SPM
Species	e^-	H^+	e^-, H^+, He^+, O^+
L Range	$0.98 < L^* < 12.4$	$0.98 < L^* < 12.4$	$2 < L_m < 10$
Energy Range	40 keV – 10 MeV	100 keV – 400MeV (V1.0-V1.05) 100keV – 2 GeV (V1.20)	e^- : 1 -40 keV H^+, He^+, O^+: 1.15 – 164 keV

- **AE9/AP9 covers trapped radiation over full range of orbit regimes**
- **SPM introduces coverage of plasma energies and species**
- **AP9 V1.20 will extend energy range up to 2 GeV, based on Van Allen Probe observations**

Range of Near-Earth Particle Hazards





AE9/AP9/SPM Suite Energy Range Coverage (trapped particles only)

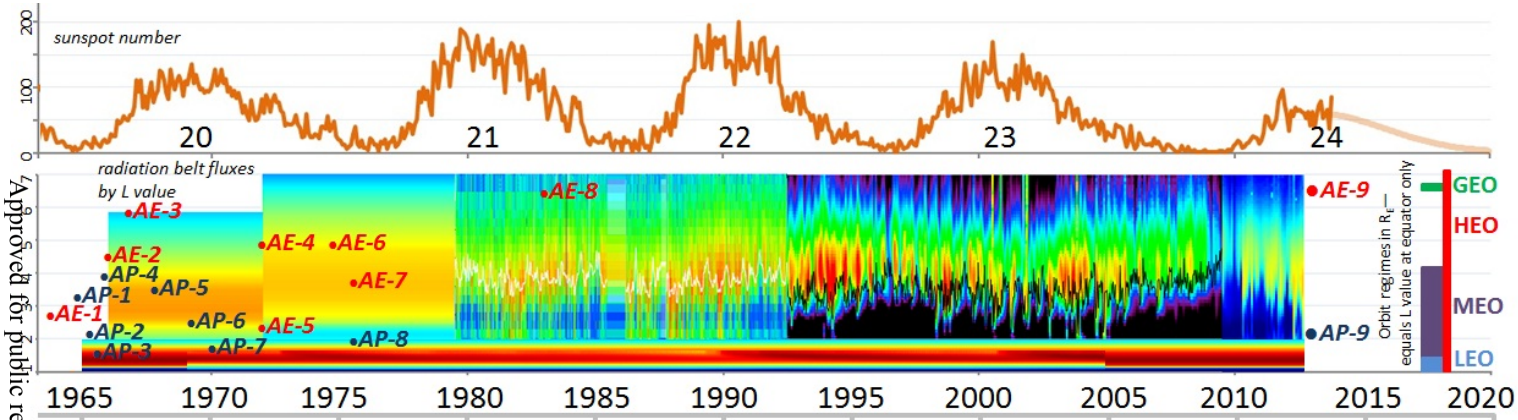
AE9/AP9/SPM Incorporates High-Quality Data Sets

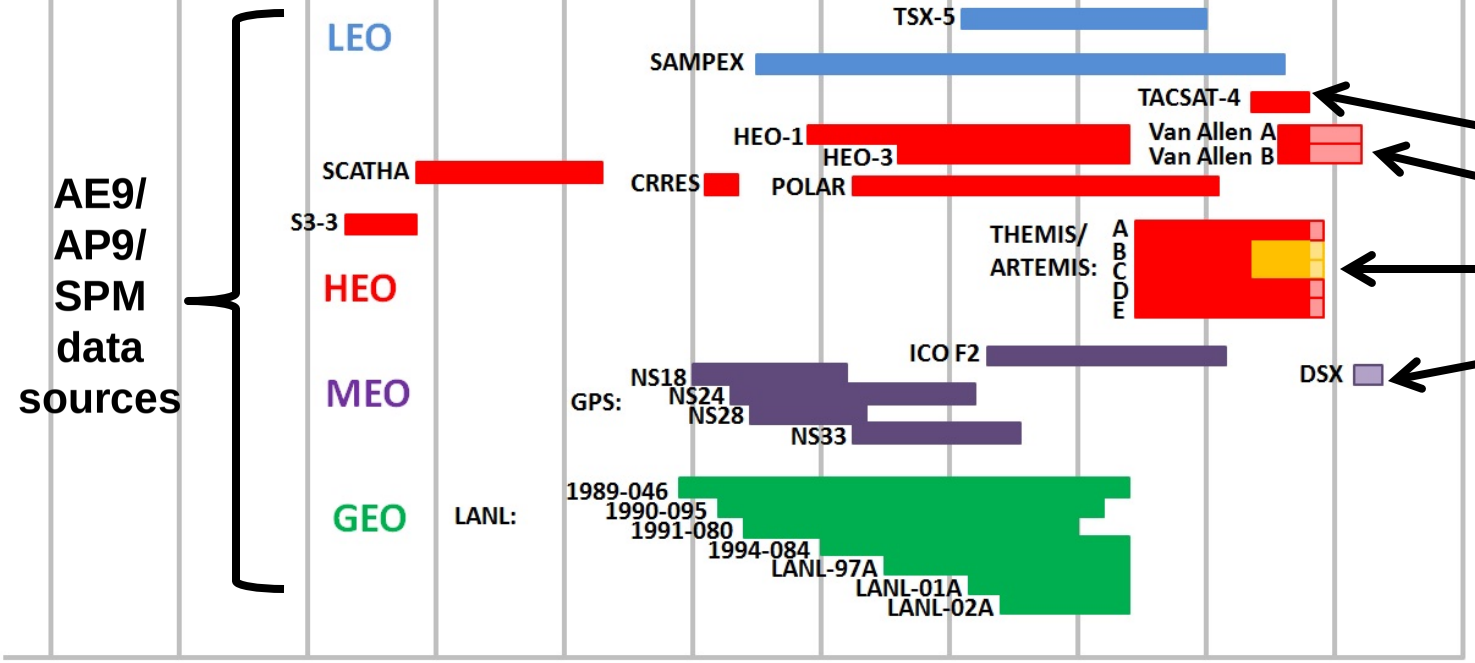
The AE9/AP9/SPM suite is based on data sets mostly acquired after development of AE8 and AP8 and covers greater spatial and energy ranges than the prior models

- Maps of the particle fluxes are created from these data sets
- Estimates of uncertainties include both measurements uncertainties and space weather variability

- AE9/AP9/SPM incorporates 33 data sets measured by space-based sensors
- Data sets were selected for accuracy in inner magnetosphere
- Data during solar proton events were eliminated
  - resulting maps describe trapped radiation only
- Cross-calibration was done to a single standard sensor, both eliminating relative biases and providing estimates of measurement uncertainty

Data Sets Used for AE9/AP9/SPM

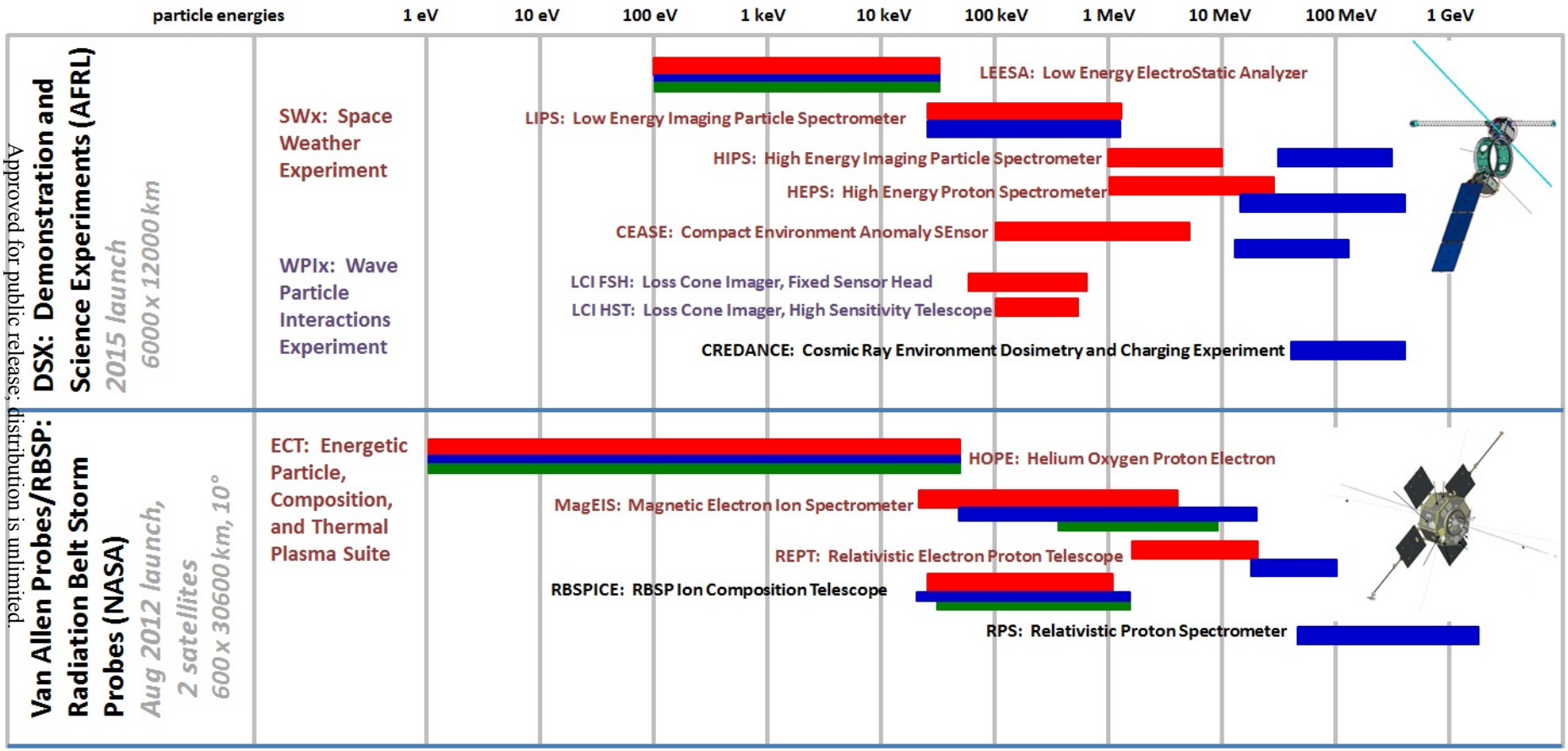




Most data sets used cover min+max solar cycle conditions

Will be used in future versions

Examples of Future AE9/AP9/SPM Data Sets

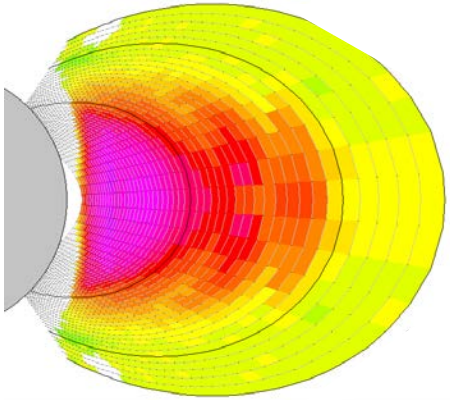


Key:

Electron Energies
Proton Energies
Ion Energies

AE9/AP9/SPM Architecture Overview

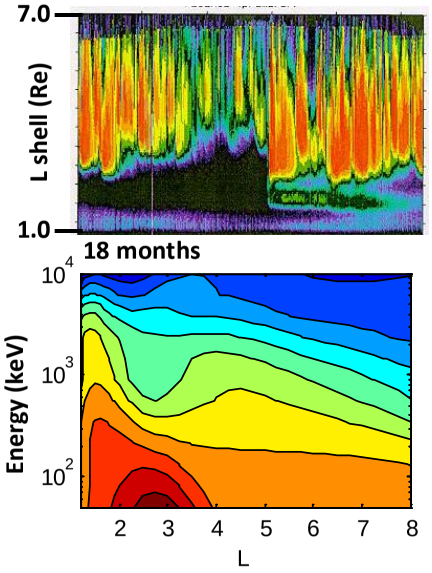
AE9/AP9/SPM Creates Flux Maps based on Satellite Data



- Creates maps for median and 95th percentile of distribution function
  - Maps characterizes both nominal and extreme environments
- Includes error maps with instrument uncertainty

+

Satellite data & theory

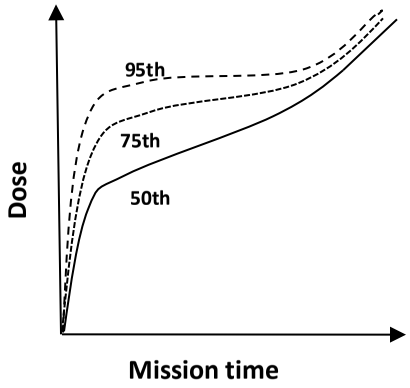


Statistical Monte-Carlo Model

- Compute spatial and temporal correlation as spatiotemporal covariance matrices
- Set up N^{th}-order auto-regressive system to evolve perturbed maps in time

=

User's orbit

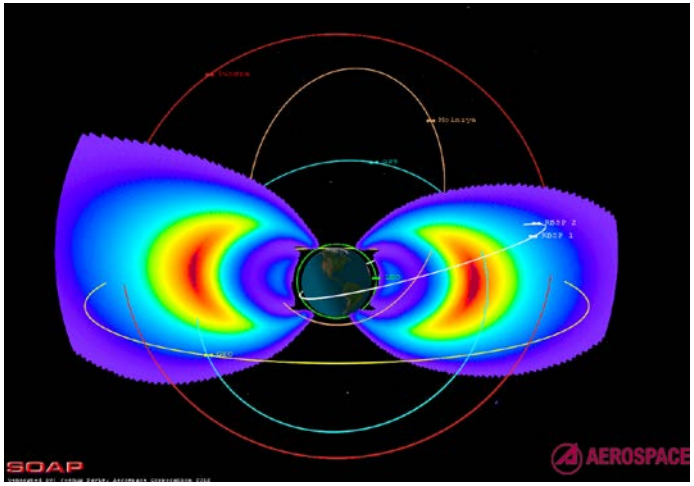


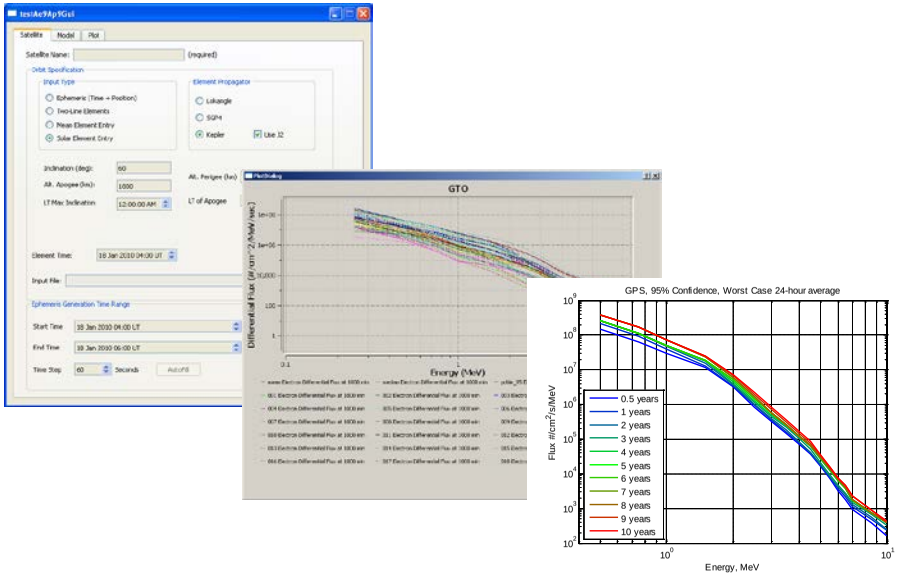
User application

- Runs statistical model N times with different random seeds to get N flux profiles
- Computes dose rate, dose or other desired quantity derivable from flux for each scenario
- Aggregates N scenarios to get median, 75th and 90th confidence levels on computed quantities

How to Use AE9/AP9

- Model provided with GUI and CmdLine access
- Specify input and options:
  - orbital elements or ephemeris
  - coordinate system
  - model(s) to use—AE9/AP9/SPM, legacy models
  - mode—e.g. mean or Monte Carlo scenarios
- Model provides requested quantities
  - fluxes, fluences, doses
- Results for appropriate modes include statistics (e.g. median and 95th percentile) for risk assessment

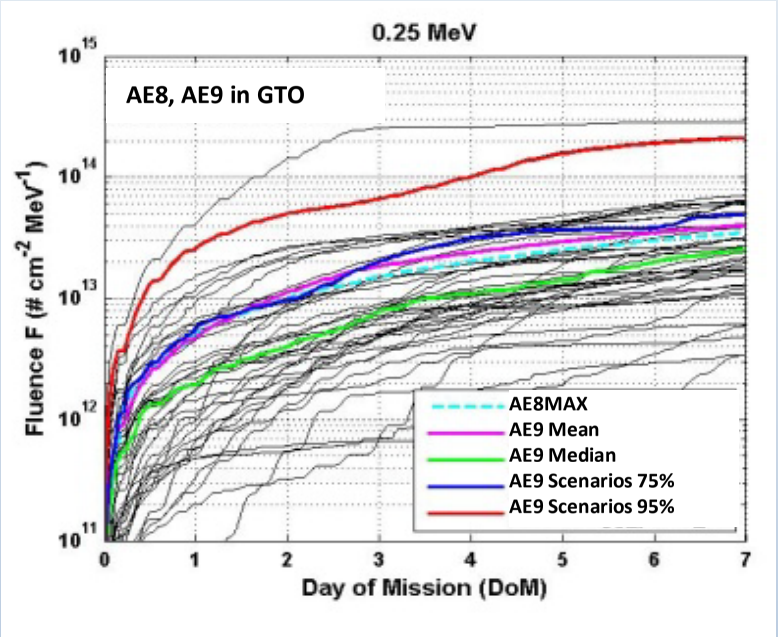




Model Comparison and Validation

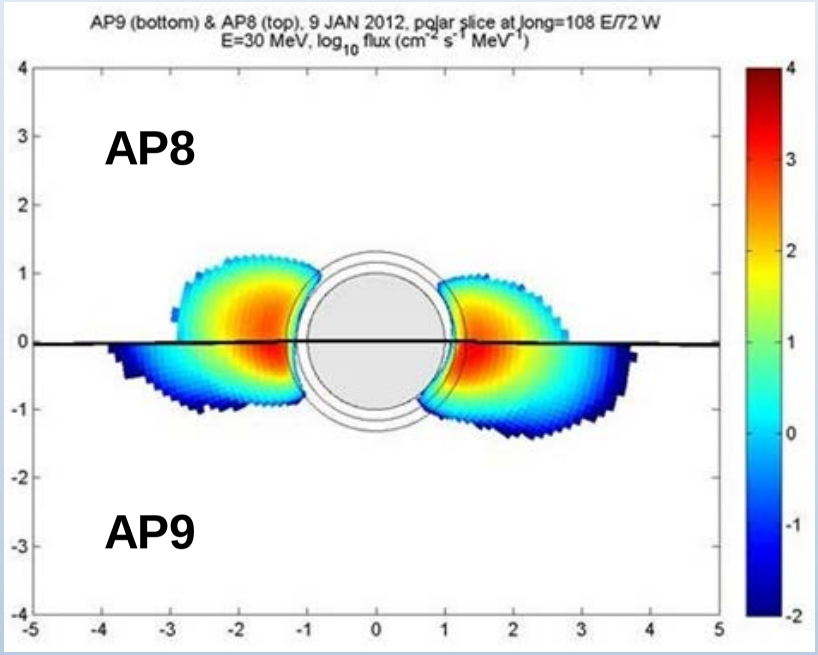
Model comparisons and validations conducted:

- **AE9/AP9/SPM results compared to legacy models including AE8/AP8**
- **AE9/AP9 results validated against independent LEO, HEO, GEO data sets**
- **Implementations of AE8/AP8 and SHIELDOSE within AE9/AP9 tool validated against results from SPENVIS and IRBEM**

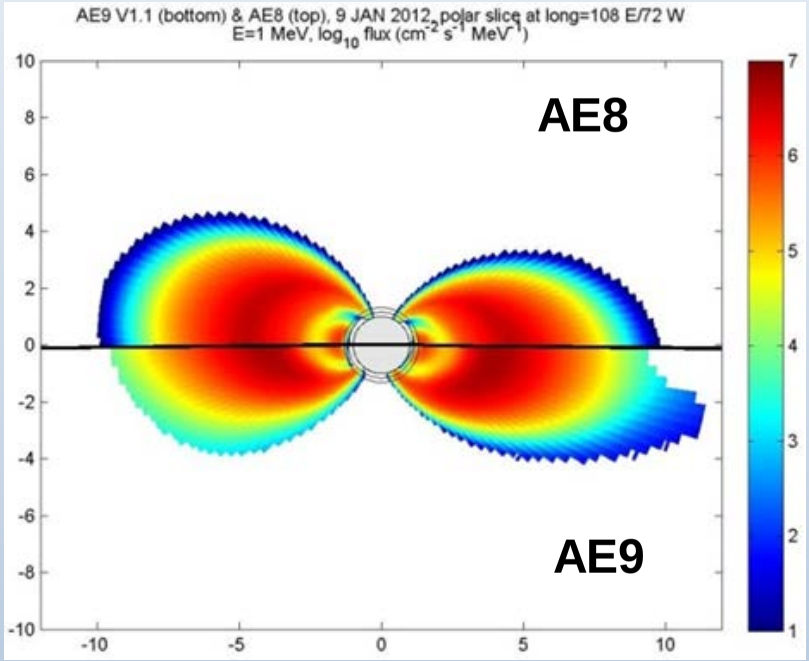


AE9/AP9 Compared to AE8/AP8

protons (30 MeV)

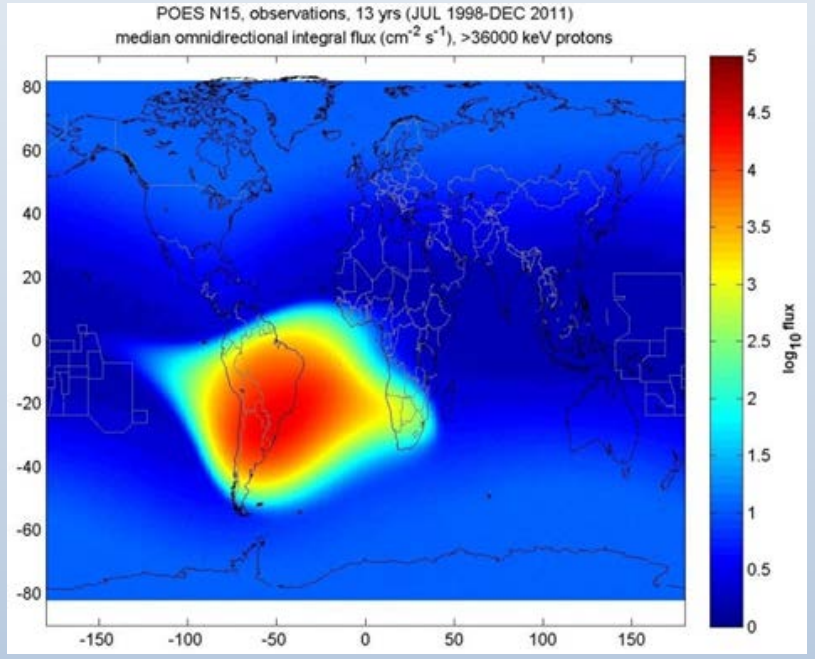


electrons (2 MeV)

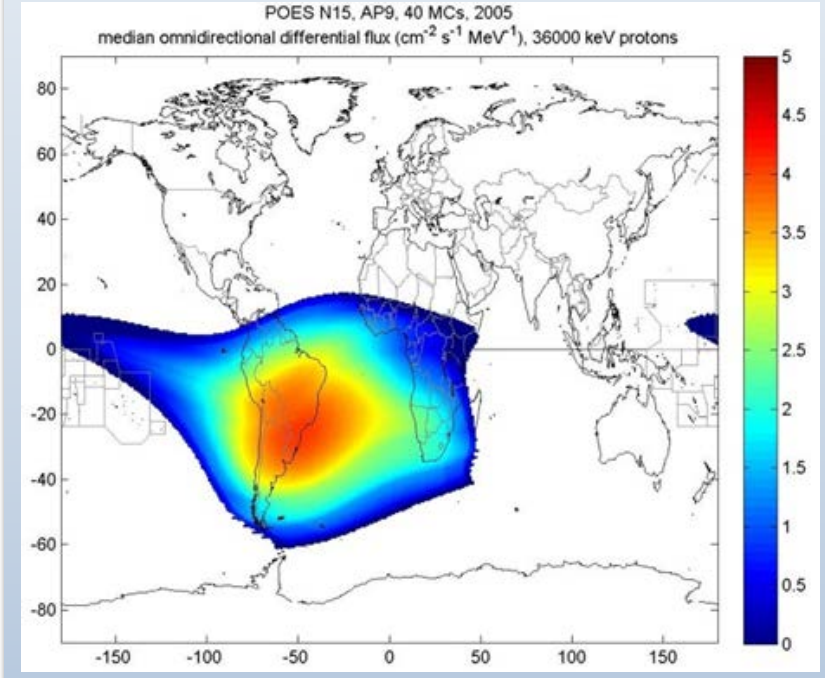


AP9 Validation—POES 15 (LEO)

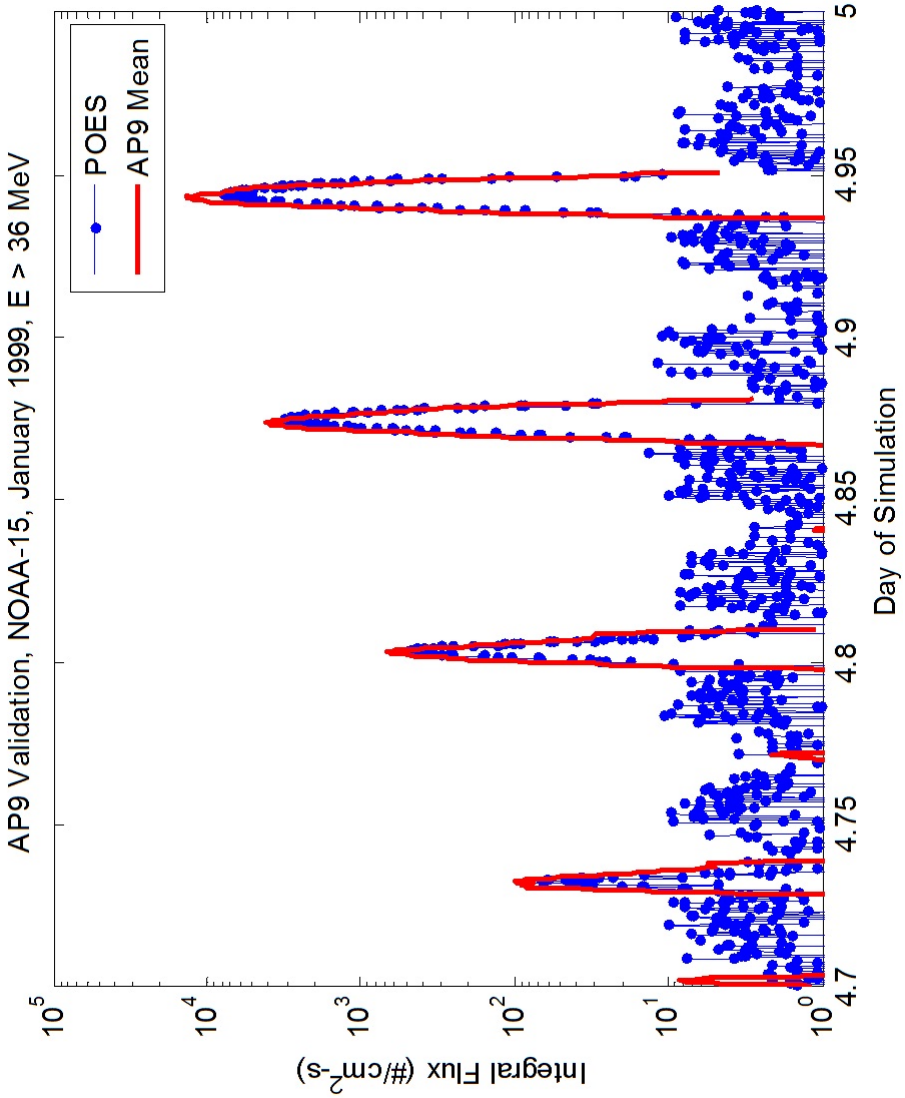
POES 15 observations, >36 MeV protons



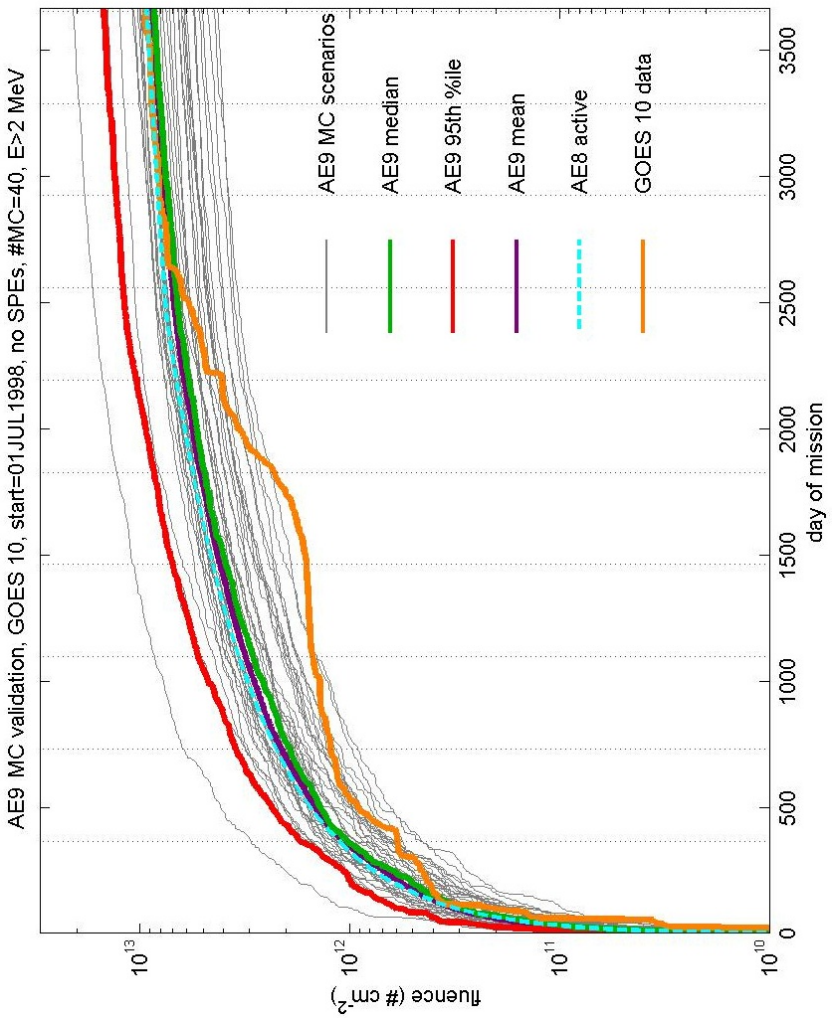
AP9 median results, >36 MeV protons



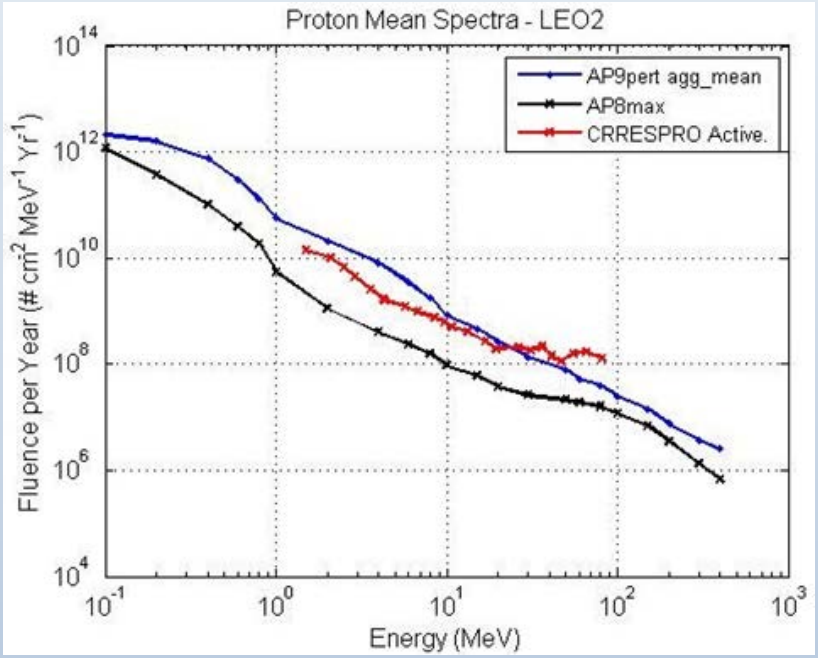
AP9 Validation—POES 15 (LEO)

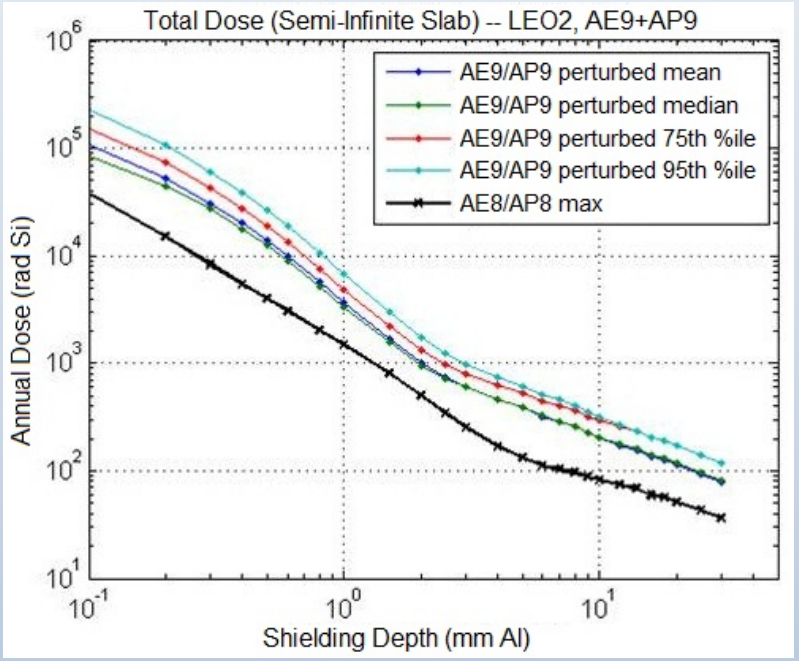


AE9 Validation—GOES 10 (GEO)

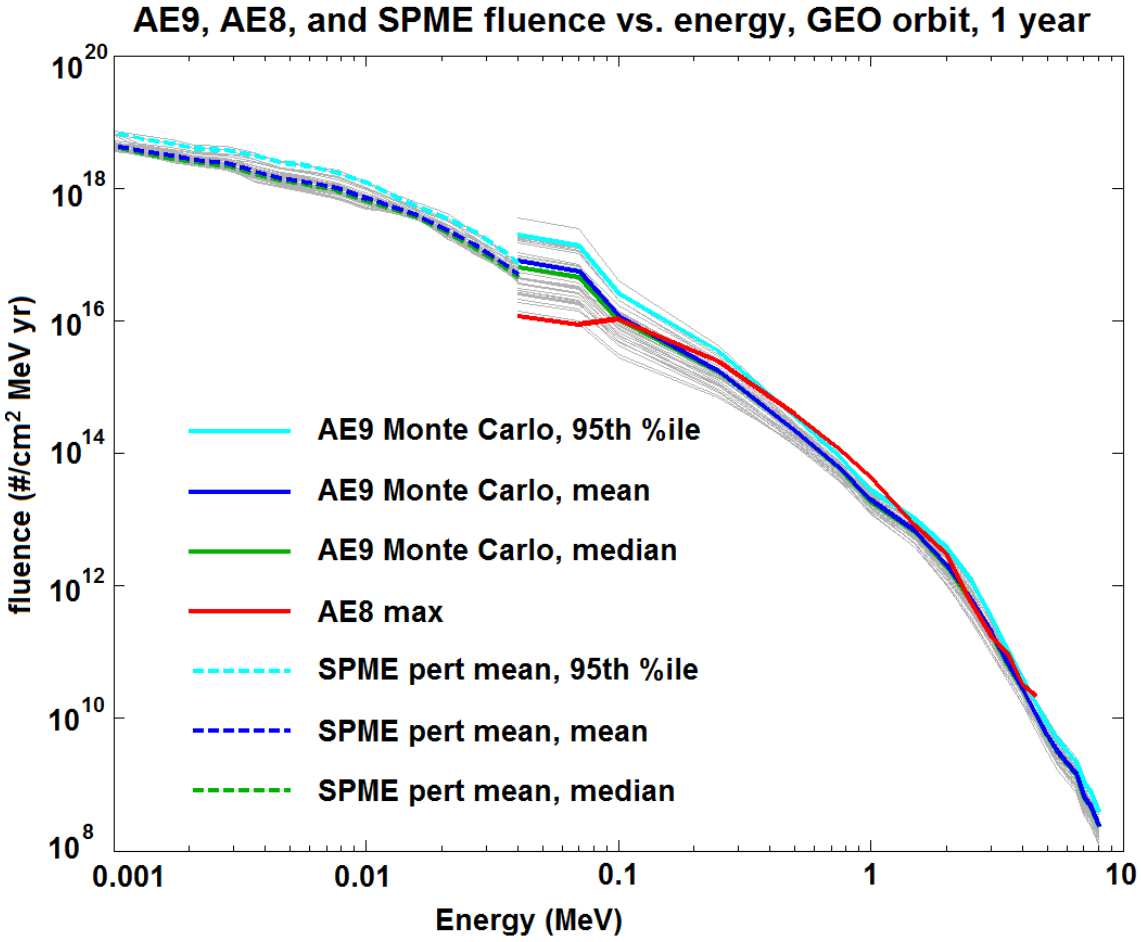


AE9/AP9 Fluence and Dose Estimates, LEO (800 km)

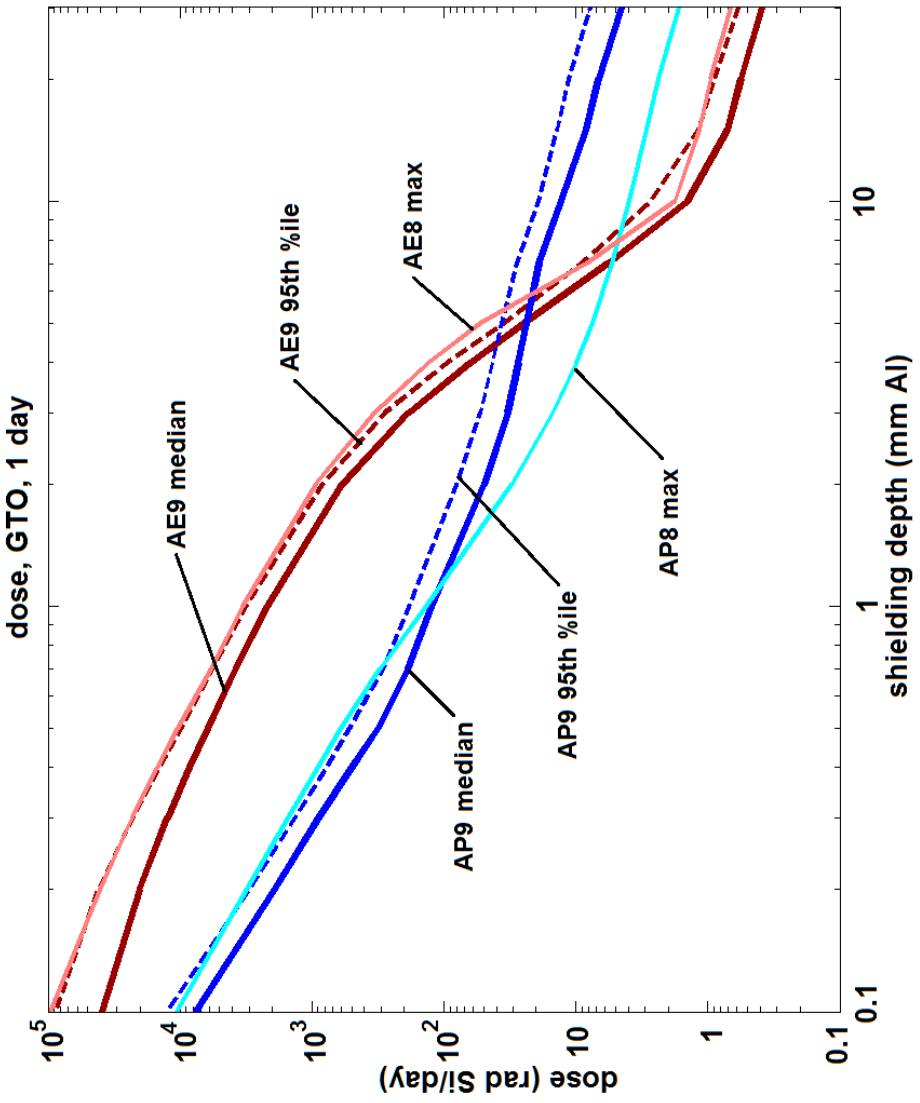




AE9/AP9/SPM Fluence Estimates, GEO

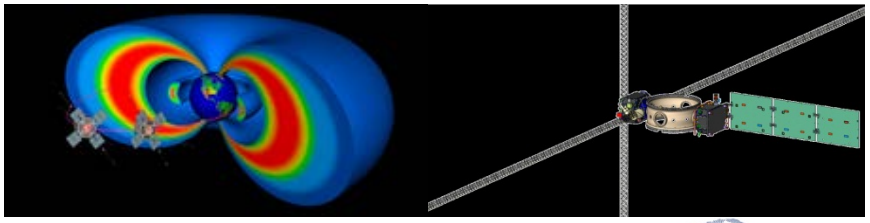


AE9/AP9 Dose Estimates, GTO



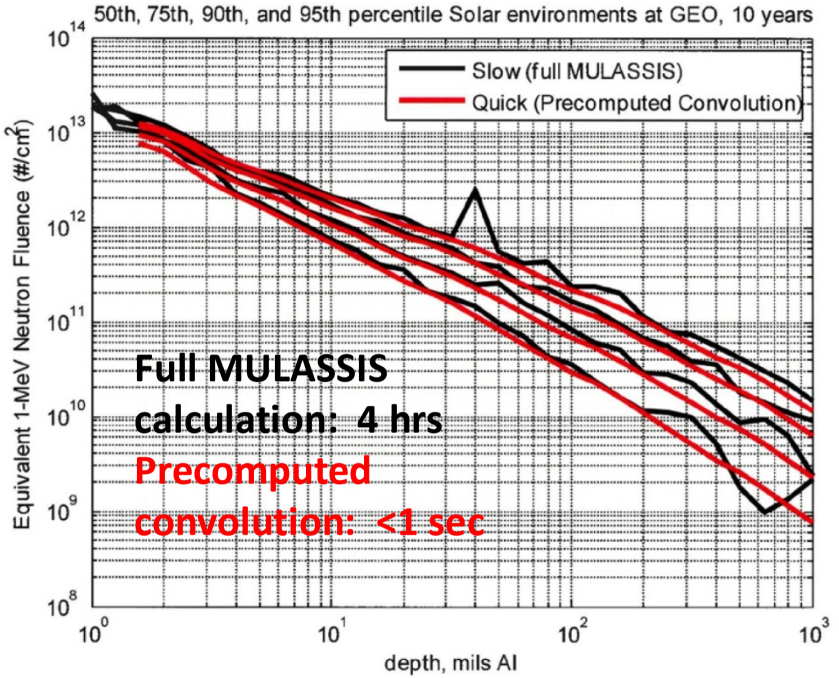
AE9/AP9/SPM
Current Version and Future Plans

- V1.0 released in 2012, current version V1.05 released in 2013
- AE9/AP9 proposed as an ISO standard trapped radiation model
- V1.2 features
  - New data: TacSat-4 protons, THEMIS plasma
  - New features: more orbit element/coordinate options, pitch angle tool
- V1.5 features
  - Parallelization capability for runs on clusters—needed to speed up long runs
  - New kernel-based effects calculation
  - New data: Van Allen Probe & Azur protons, Van Allen Probe & DEMETER electrons, SCATHA & AMPTE plasma
  - International collaborators contributions of data and models
  - Future name IRENE — International Radiation Environment Near Earth
- V2.0 and later features
  - Sample solar cycle flythrough option
  - New modules
  - New data: PAMELA, DSX/SWx, ERG



Kernel-Based Effects Calculation

- **V1.5 will include AE9/AP9 capability to use independently-calculated radiation effects for faster effects results in the AE9/AP9 environment:**
  - **User precomputes desired effect vs. depth/particle/energy for a particular material/geometry/component, using independent particle simulation code**
  - **Results are formatted as a "kernel" for import into AE9/AP9/SPM**
  - **AE9/AP9/SPM environment plus effects kernel yields rapid calculations of specific effects**
- **Sample kernel for single event effects is in development**
- **Provides ability to rapidly obtain AE9/AP9 environment effects for specific components**



O'Brien and Kwan, 2013, Aerospace Report TOR-2013-00529 A

Summary

- **AE9/AP9/SPM meets the design community's need for state-of-the-art radiation environment specification**
  - **More coverage in energy and location**
  - **Introduces statistics describing uncertainties and environment variability**
- **Plans are in place for future updates in both data and features**
  - **Architecture supports updates with new data**
  - **Future features will expanded capabilities, addressing additional hazards and more options for applying model results to design**

Contact Information

- Comments, questions, etc. are welcome and encouraged!
- Please send feedback to (copy all):
  - Bob Johnston, Air Force Research Laboratory, AFRL.RVBXR.AE9.AP9.Org.Mbx@kirtland.af.mil
  - Paul O'Brien, Aerospace Corporation, paul.obrien@aero.org
  - Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu
- Information and discussion forum available on NASA SET website:
  - http://lws-set.gsfc.nasa.gov/radiation_model_user_forum.html
- The model will eventually be available for web download
  - In the meantime contact Gregory Ginet, MIT Lincoln Laboratory, gregory.ginet@ll.mit.edu

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